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Identification and Classification of Combustion Source Equipment

Processes Research, Inc.

prepared for
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Identification and Classification of Combustion Source Equipment

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16. Abstracts: The report classifies approximately 130 types of stationary fuel-burning equipment that can emit air pollutants. It presents more detailed information (including fuels, sizes, processes, industries, products, and manufacturers) on gas turbines and kilns. Gas-turbine-related facts reported include: present installed capacity should double in the next 5-9 years; present national fuel use is about 1 to 1-1/2% of the total consumption of natural gas and oil; and the major pollutant is NOx, with smoke a secondary, more controllable contaminant. Kiln-related facts, somewhat limited, include: growth rates of related industries are low, except for being moderate in the lime industry; present total national fuel use is about 1/2 to 1% of the natural gas and oil, and about 2 to 2-1/2% of the bituminous coal (cement and lime industries account for more than 75% of the gas and oil, and nearly all of the coal consumed); and there is almost no emissions data available.

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*Equipment
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Natural Gas
Oils
Kilns
Gas Turbines
Nitrogen Oxides
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Identification and Classification of Combustion Source Equipment

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IDENTIFICATION AND CLASSIFICATION

OF

COMBUSTION SOURCE EQUIPMENT

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SECTION I - INTRODUCTION AND SCOPE

This report summarizes results of work performed under Environmental Protection Agency (EPA) Task Order No. 6, Contract 68-02-0242, with Processes Research, Inc. (PR). The general purposes of the work were to identify and classify types of stationary fuel-burning equipment which can produce air pollutant emissions and to obtain more detailed information on two types of such equipment; namely, gas turbines and kilns.

The scope was specifically defined as follows:

Phase I: Develop a comprehensive list of stationary combustion equipment.

Phase II: Analyze gas turbines and kilns in detail and classify the various types and subtypes according to such factors as fuels burned, unit size, processes and industries in which used, products for which applied, manufacturers of the equipment, and other appropriate elements. Include in the analysis a discussion of the relative importance of the processes as sources of NO_x emissions and other pollutants produced.

The project approach for Phase II included an extensive search of technical and commercial literature, contacts with manufacturers and trade associations, and subsequent analysis and classification of the data and information obtained. The approach for Phase I was similar except that it did not include contacts with manufacturers and trade associations.

SECTION II - SUMMARY OF RESULTS

A. LIST OF STATIONARY COMBUSTION EQUIPMENT - PHASE I

Tabulated in Section III is a comprehensive list of stationary combustion equipment developed by this study. This list contains approximately 130 different items of equipment classified by technical and functional features.

This list can be used by EPA as a guide in selecting the types of equipment requiring more detailed investigation. The detailed investigations of gas turbines and kilns, developed under Phase II of this study and summarized in Sections IV and V, represent the level of investigation which may be desirable for many of the other items shown on this list.

B. GAS TURBINES - PHASE II

The field of gas turbines was subjected to detailed investigation and analysis as specified by the scope of the task order. Extensive and useful information was found in this investigation which has facilitated identification and classification according to type, size, functional use, industry in which used, fuels, and manufacturers. This information is discussed and summarized in Section IV and Appendix A.

Installed capacity of gas turbines has shown a rapid growth over the past ten years. Projected future growth indicates a doubling of present installed capacity within the next five to nine years. An order-of-magnitude estimate of present fuel usage indicates that gas turbines may now account for about one to one and one-half percent of the total national consumption of natural gas and oil.

Because of their basic design and construction, gas turbines must burn clean fuel or fuel relatively free of sulfur, ash, vanadium and other such impurities.

A large research effort has already been expended on the air pollution aspects related to the use of gas turbines in transportation. This effort indicates that the major pollutant is NO_x with smoke as a secondary, but presently more controllable, contaminant. It also indicates that other pollutants show very low emission factors in comparison with those from internal combustion engines. The approach to control of the NO_x emission is presently centered on design and control of the combustor elements of the turbine system. This is discussed in further detail in Section IV E.

Future work in this field should involve (1) the obtaining of emission measurements on various sizes and types of stationary installations, and (2) continuing research on improving combustor design and controls to adequately control NO_x and other emissions both at present operating temperatures and at the higher future contemplated operating temperatures.

C. KILNS

The field of kilns was subjected to the same investigation and analysis as gas turbines. Information for this category was found to be widely scattered and somewhat limited. This information, although less comprehensive than that for gas turbines, was classified according to the same general factors and is discussed and summarized in Section V and Appendix B.

Generally, kilns are used for vitrification of preformed shapes, and for high temperature chemical processing of bulk materials. Kilns are used in virtually all processing in the vitrification, cement and lime industries. The

indicated growth rates of these industries are generally low, except that for the lime industry which is moderate. An order-of-magnitude estimate of their total present fuel consumption is between one-half and one percent of the national consumption of natural gas and oil, and between two and two and one-half percent of the national consumption of bituminous coal. The cement and lime industries account for more than three fourths of this oil and gas consumption and virtually all of this coal consumption.

Rotary kilns are used in various steps of processes in many other areas of the chemical industry. No estimates are presently available of the product capacity of such kilns or of their fuel usage, although it is believed to be substantial.

Apparently very little work has been done to determine emission factors and measures for control of air pollutants from kilns. Some work has been reported for clay, unglazed brick, and cement industries.

In examining pollutant emission from kilns, most of which are direct fired, consideration must be given to pollutants from the raw materials in the process, as well as those from the combustion necessary in firing the kiln. It is believed that the flue gases will contain the same pollutants normally emitted by combustion of fossil fuels within a furnace, varied somewhat by the design and operating temperatures of the kiln, and will include, in some cases, particulate and other pollutants from the raw materials and products related to the process. Information on possible pollutants from these processes is contained in Section V D 6 and Appendix B.

The almost complete lack of data concerning emissions from kilns makes it imperative that reliable field data be obtained before intelligent consideration can be given to programs for corrective action.

SECTION III - LIST OF STATIONARY COMBUSTION EQUIPMENT

Included in this section of the report is a comprehensive list of stationary combustion equipment developed as Phase I of this study.

This list is based on extensive literature source search comprising publications in the fields of chemical and metallurgical engineering, of commercial listings and of various reports prepared by and/or for EPA. Classification of items within the list was based on similarity of technical and functional features of the equipment.

It is believed that this list represents virtually all of the major items of combustion equipment in use at the present time.

LIST OF STATIONARY COMBUSTION EQUIPMENT

Task No. 6 -- Contract No. 68-02-0242

The following equipment items are listed alphabetically for each major type with subtypes listed secondary to the major type. Supplementary explanatory notes are included where appropriate.

Equipment Type	Subtype
Afterburners	Catalyst
Afterburners	Direct Fired
Air Conditioners	Industrial - Gas
Baths	Heat Treating and Tempering (Oil, salt, lead, etc.)
Baths	Metal Coating (Galvanizing and other)
Boilers - Steam	Fire Tube
Boilers - Steam	Water Tube: Less than 100,000 pounds steam per hour 100,000-250,000 pounds steam per hour 250,000-500,000 pounds steam per hour Over 500,000 pounds steam per hour
Boilers - Steam	Cast Iron
Boilers - Steam	Tubeless - Steel Shell
Boilers	Carbon Monoxide (Petroleum refining)
Boilers	Thermal Liquid Heat Transfer Systems
Calciners Catalyst Regenerators	(Petroleum refining)
Dryers	Continuous Web - Impingement Type
Dryers	Continuous Web - Through Type
Dryers	Drum
Dryers	Flash Solids
Dryers	Fluidized Bed
Dryers	Laundry - Commercial
Dryers	Laundry - Domestic
Dryers	Multi-louvre (Cascade)
Dryers	Paint and Varnish (After application)
Dryers	Pneumatic Conveyor
Dryers	Rotary
Dryers	Rotary - Roto - Louvre
Dryers	Spray
Dryers	Tray Rack as Compartment - Batch
Dryers	Tunnel - Moving Truck or Tray Rack
Dryers	Turbo - Tray (Multi-rotary Tray)
Dryers	Vibrating Conveyor

Equipment Type	Subtype
Flame-cutting machines	
Flame-welding and brazing machines	
Flare Stacks	(Petroleum refining)
Furnaces-Static Bed-Nonmelting -	Car Bottom - Batch
Furnaces-Static Bed-Nonmelting -	Cover - Batch
Furnaces-Static Bed-Nonmelting -	Muffle - Batch
Furnaces-Static Bed-Nonmelting -	Open Chamber or Compartment - Batch
Furnaces-Static Bed-Nonmelting -	Pit (Soaking pit and smaller)
Furnaces-Static Bed-Melting -	Converters (Bessemer type)
Furnaces-Static Bed-Melting -	Crucible
Furnaces-Static Bed-Melting -	Pot
Furnaces-Static Bed-Melting -	Reverberatory - Open Hearth
Furnaces-Static Bed-Melting -	Reverberatory - Smelting
Furnaces-Static Bed-Melting -	Reverberatory - Glass
Furnaces-Static Bed-Continuous -	Car - Continuous
Furnaces-Static Bed-Continuous -	Conveyor
Furnaces-Static Bed-Continuous -	Conveyor Blast Sintering
Furnaces-Static Bed-Continuous -	Lehr (Glass annealing)
Furnaces-Static Bed-Continuous -	Pusher - Continuous (Billet)
Furnaces-Static Bed-Continuous -	Rotary Hearth
Furnaces-Static Bed-Continuous -	Tunnel
Furnaces-Moving Bed-Continuous -	Mannheim Rotary Hearth
Furnaces-Moving Bed-Continuous -	Multiple Hearth
Furnaces-Moving Bed-Continuous -	Multiple Hearth - Suspension Roaster
Furnaces-Moving Bed-Continuous -	Rotary - Direct Fired
Furnaces-Moving Bed-Shaft	Blast
Furnaces-Moving Bed-Shaft	Cupola
Furnaces-Moving Bed-Shaft	Pebble
Furnaces-Moving Bed-Shaft	Spouted Bed
Furnaces-Fluid Bed -	Non-catalytic Reactor
Furnaces-Fluid Bed -	Catalytic Reactor
Furnaces-Fluid Bed -	Multiple Stage Reactor
Furnaces-Fluid Bed -	Fluid Column Roasting
Furnaces-Pneumatic -	Screw Conveyor
Furnaces-Pneumatic -	Vibrating Conveyor - Flow Through Direct
Furnaces-Pneumatic -	Flash Solids Roasting
Furnaces-Carbon -	Channel Black
Furnaces-Carbon -	Thermal Black
Furnaces-Carbon -	Graphite - Ring
Furnaces-Hot Air -	Commercial
Furnaces-Hot Air -	Domestic
Furnaces-Hot Air -	Industrial

Equipment Type	Subtype
Generators	Gas - Fuel Producer
Generators	Gas - Chemical Processing (SO_2 Paper)
Generators	Gas - Inert (Petroleum refining)
Heaters	Hot Water - Commercial
Heaters	Hot Water - Industrial
Heaters	Hot Water - Swimming Pool
Heaters	Process - Hot Water and Steam
Heaters	Process - Liquid Chemical
Heaters	Process - Pebble
Heaters	Railroad Car
Heaters	Space or Unit
Heaters	Mold and Die
Incinerators - Refuse	Conical - (Includes wood disposal)
Incinerators - Refuse	Domestic - Simple Type
Incinerators - Refuse	Flue Fed - (Apartment house type with chute)
Incinerators - Refuse	Industrial-Commercial - Single or Multi-Chamber (With manual or automatic charge)
Incinerators - Refuse	Municipal - Multiple Chamber - Automatic Charge
Incinerators - Refuse	Municipal - Rotary - Automatic Charge
Incinerators	Auto Body - Batch
Incinerators	Auto Body - Continuous
Incinerators	Pathological and Cremation
Kettles	Direct Fired
Kilns	Circular - (Continuous)
Kilns	Box - Muffle
Kilns	Rotary
Kilns	Round - Downdraft
Kilns	Round - Updraft
Kilns	Shuttle - Car
Kilns	Shuttle - Conveyor
Kilns	Tunnel - Car
Kilns	Tunnel - Conveyor
Kilns	Vertical Shaft
Ovens	Coke - Beehive
Ovens	Coke - By-product
Ovens	Cooking (Oven and/or Stove) - Commercial
Ovens	Cooking (Oven and/or Stove) - Domestic
Ovens	Rack
Ovens	Shelf
Ovens	Tunnel - Car
Ovens	Tunnel - Conveyor
Ovens	Circular - (Continuous)

Equipment Type	Subtype
Reciprocating Engines	Diesel - Precompression Chamber - Not Supercharged
Reciprocating Engines	Diesel - Precompression Chamber - Supercharged
Reciprocating Engines	Diesel - Direct Ignition - Not Supercharged
Reciprocating Engines	Diesel - Direct Ignition - Supercharged
Reciprocating Engines	Gas or Gasoline - Spark Ignition - Not Supercharged
Reciprocating Engines	Gas or Gasoline - Spark Ignition - Supercharged
Refinery Clay Filters	(For color control)
Refinery Delayed or Fluid Coking Unit	
Retorts	Metal Refining
Retorts	Coke
Retorts	Charcoal
Stills	Tube or Pipe - (Primarily petroleum furnaces used in catalytic cracking)
Stills	Kettle
Turbines	Gas - Open Cycle - Simple
Turbines	Gas - Open Cycle - Regenerative
Turbines	Gas - Combined Cycle - (Simple or Regenerative Cycle combined with exhaust heat recovery)

SECTION IV - GAS TURBINES

The term gas turbine can be defined as a rotary engine actuated by the reaction or impulse of a pressurized and expanding current of gas, generated from combustion of fuel, and acting on a series of curved blades mounted on a rotating spindle.

Most of the analysis and classification developed in this section is based on an extensive literature search which yielded moderately complete and satisfactory information. This information has, in turn, enabled a clear cut treatment outlined in the following pages.

A. TYPES, SIZES, MANUFACTURERS AND TRADE ASSOCIATIONS

1. Types. The major subtypes of gas turbines are listed on page 1 of Appendix A. These may generally be described as follows:

a. Open Cycle - Simple. No exhaust heat recovery equipment is employed. This system includes a rotating compressor for pressurizing atmospheric air, a combustor or furnace where the compressed air is mixed with fuel and burned, and a turbine where the hot gases are expanded against the turbine blades to generate rotational motion. The expanded hot gases are then exhausted directly to the atmosphere.

b. Open Cycle - Regenerative. This system employs a regenerator or heat exchanger between the compressor and combustor through which the exhaust gases are circulated to heat the incoming air to the combustor. This, of course, uses some of the heat which would normally be exhausted, thereby reducing fuel consumption. Thermal efficiency, consequently, is increased approximately five to ten percent above that of the simple system.

c. Combined Cycle. In this system, the exhaust gases are routed directly from the turbine to a boiler where steam is generated for further production of power or for process uses. This results in increasing thermal efficiency approximately ten to fifteen percent above that of the open cycle - simple system.

There are further variations within each of the subtypes which are not significant for this report.

The open cycle - simple type is by far the most widely used. It requires the least investment and is the most flexible in application. The other types are less generally used, especially where the usage requirements are very intermittent, such as for standby power. The combined cycle appears to be gaining acceptance among power utilities for base power and extended peaking requirements, and predictions are that it will become much more widely used in the future.

2. Size Ranges. The size ranges are shown on page 1 of Appendix A. Capacities of the largest units manufactured have been increasing with some units in the range of 134,000 to 268,000 horsepower output (100 to 200 MW). In the largest size category, however, the average size of units sold in the 1968 to 1970 period was between 35,000 to 40,000 horsepower.

3. Manufacturers. Manufacturers of gas turbines are listed on page 2 of Appendix A. This tabulation is not necessarily all-inclusive but does represent the currently active manufacturers of most of the stationary gas turbines sold in the United States in the last few years. It should be noted

that most of these manufacturers appear to have only certain size ranges in which they are primarily active.

4. Trade Associations. Page 50, Appendix A, gives a listing and description of trade associations and technical organizations related to, or involved in, the gas turbine industry.

B. USES BY FUNCTION AND INDUSTRY

The various uses of gas turbines by function and industry classification are shown on Pages 51 and 52, Appendix A. In general, their functional uses are as motive power for electric power generation, direct compression of gases and direct pumping of liquids. In many cases, the power generated has a captive and specific use; e.g., operating pumps and supplying general power requirements on an offshore oil well drilling platform.

The industries in which gas turbines are used, as shown on the list, are those containing most of the installed capacity. Because of the relatively low capital cost of gas turbines, general industrial and commercial use is continuing to expand, primarily for captive power generation. The number of industries in which they are used will therefore also continue to expand.

It is to be noted from the list that the major uses of gas turbines, and industries in which they are used, are as follows:

Use	Industry	Combination 1969 and 1971 Estimate of Capacity
Electric power	Electric companies and systems	42.2 million hp
Gas compression	Natural gas transmission	2.2 million hp

Usage in the remainder of the listed industries is believed to be relatively small although no statistics have been located giving installed capacity in such other industries.

Geographic location of gas turbines used in the electric companies and systems industry would follow the location of power plants in general; namely, close to large metropolitan centers. Location of those used in the natural gas transmission industry would, correspondingly, be along the transmission lines of that industry and would be in primarily rural areas.

C. INDUSTRY INFORMATION ON MARKETS AND GROWTH

Although statistics on installed gas turbine capacity and expected growth rates are incomplete, a reasonable indication of this can be found from the summary on Page 53, Appendix A. The number (population) of units sold during the years 1965 through 1969 is believed to represent about one half the total installed capacity at the end of 1969. Growth rates based on existing installed capacity were then projected from some available industry projections of unit sales which resulted in compounded growth rates of twelve to fourteen percent for all turbines above 10,000 horsepower. Another projection indicates that the compounded growth rate will be about 8.2 percent per year from 1970 to 1978. Using both estimates, it can be projected that the total estimated installed capacity of over forty-five million horsepower in 1971 would double in five to nine years.

Strong conflicting factors affect this growth picture insofar as the electric power industry is concerned. Factors tending to increase growth are:

1. Growing popularity of combined cycle gas turbine plants.

2. Pollution restrictions which affect conventional type power plants (boilers) more severely than combined cycle plants, because of the higher rates of pollutant emissions from boilers.

Factors tending to decrease growth are:

1. Increasing use of atomic energy.

2. Other factors, such as development of coal gasification, which could overcome many of the pollution problems of conventional type power plants.

D. FUELS AND COMBUSTION

1. Fuels and Fuel Usage. The primary fuels used in gas turbines are natural gas and light and heavy distillate oil. There is a small usage of residual oil, but this use is severely restricted because of contaminants present in such oil. When heavy oil and residual oil is used, it generally must be treated to remove most of the sulfur and vanadium content, both of which have a severe corrosive effect on turbine blades. There is also some usage of chemical processing waste gases as fuel. There has been some experimentation in the use of pulverized coal, with little apparent success because of blade erosion and deposition problems resulting from ash and other contaminants.

The prospects for expanding usage of fuels, other than natural gas and distillate oil, appear to be satisfactory only for residual oil treated to remove sulfur and other impurities. There does not appear to be much prospect for the other fuels mentioned above to become major usage factors.

A summary of the types of fuel used by various industries is shown on Page 54, Appendix A. It should be noted that usage in certain industries

is generally limited to certain types of fuel; e.g., the natural gas transmission industry will use primarily natural gas because of its low cost and availability. In many applications, gas turbines are equipped to use either natural gas or oil and this is so indicated in the summary.

The order-of-magnitude estimate of total national fuel consumption for gas turbines is shown on Page 55, Appendix A. At the 1971 level of capacity, it is estimated that 100 million pounds of fuel would be burned per day. Based on fuel consumption data on gas turbines from the Federal Power Commission showing the relationship between oil and gas usage, this would amount to a consumption of:

Oil = 182,000 barrels per day

Natural gas = 880 MM cubic feet per day

It is estimated that in five to nine years this rate will triple.

The above 1971 figures represent about one percent of the national consumption of oil and about one and one-quarter percent of the national consumption of natural gas, as shown on Page 56, Appendix A.

2. Combustion. As mentioned previously, combustion in a gas turbine system occurs in the combustor or furnace. Figure 1, Page 17, shows a general arrangement of a combustor and zones of combustion. Combustion in the primary zone occurs at a temperature of around 3500F. The gases are then quenched by air or gas to a temperature which the turbine blades can tolerate. For most currently used turbines, this is in the range of 1500F to 1800F. In order to increase thermal efficiencies, continuing efforts are being made by turbine manufacturers to increase this temperature. The near term objective is 2000F to 2200F and that for the long term, 3000F.

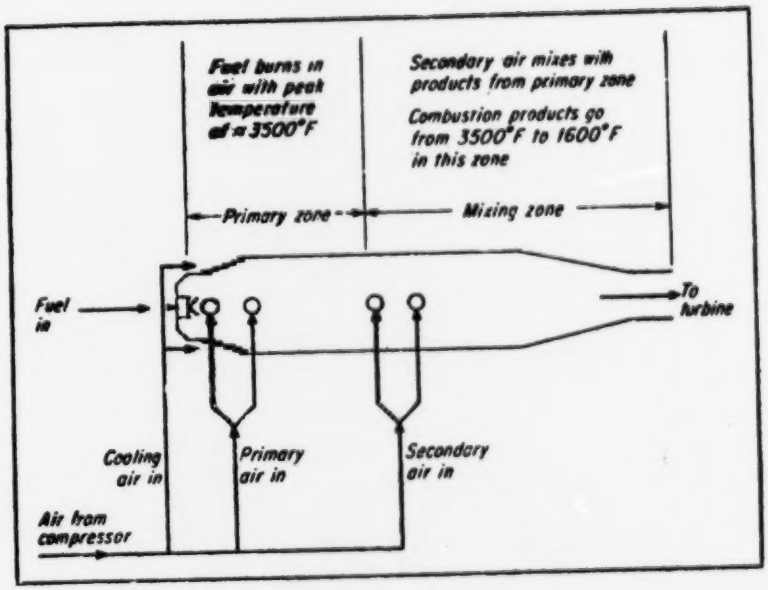
Fuel burns in air with peak temperature of ≈ 3500°F
Secondary air mixes with products from primary zone
Combustion products go from 3500°F to 1600°F in this zone
Primary zone
Mixing zone
Fuel in
To turbine
Cooling air in
Primary air in
Secondary air in
Air from compressor

Figure 1. Diagram - Gas Turbine Combustor

There are basically two types of turbine combustors, annular and canannular. The annular combustor consists of an outer liner and an inner liner shrouding the engine centerline. The canannular type of combustor consists of burner liners or "cans" being placed in an annulus which is arranged around the engine centerline. The annular combustor has the advantage of having a greater surface area to volume ratio than the canannular combustor resulting in higher combustion efficiency. It has the disadvantage of being more difficult to maintain and repair. It has been concluded by experts in the field that combustor design has no effect upon emissions levels. A great deal of the information on combustor design and related emission levels is already existent in the "Federal R&D Plan for Air Pollution Control by Combustor Process Modifications," Final Report CPA-22-69-147, January 11, 1971.

E. AIR POLLUTION FACTORS AND CORRECTIVE POSSIBILITIES

1. General. A search of current literature indicates that a substantial amount of research has been focused on the air pollution aspects of gas turbines. Much of this has been related to the use of gas turbines in ground and aircraft transportation. It appears, however, that much of the data developed are basic to the turbine itself and are applicable to stationary equipment as well.

According to several sources, the major pollutant emitted from gas turbines is NO_x with a secondary pollutant being smoke (primarily unburned carbon). Other pollutants are said to have lesser significance.

A compilation of data published in Engineering for Power, October 1969, by Sawyer, Tiexeira and Starkman titled "Air Pollution Characteristic of Gas Turbine Engines" shows the following:

Table 1. Exhaust Emissions from Selected Engines (Reported as an "Emission Index," mg species/g fuel)

Engine	CO	HC (as Hexane)	NO
Spark ignition, 30 mph	241	6.1	16.3
Spark ignition, cold start	513	35	14.5
Spark ignition	407	35	13
Regenerative gas turbine, 30 mph	5.3	0.3	13.5
Gas turbine, cold start	50	1.1	9.8
Aircraft turbojet	3.3	0.4	5.5
Aircraft turbojet	19	2	5

When comparing engines running at 30 mph in the above chart, the CO and HC pollutants of a gas turbine are two to five percent of what they are in a spark ignition engine.

A very rough order-of-magnitude estimate of total emissions can be computed from the estimated emission factors in Table 1 and the 1971 fuel consumption, Page 55, Appendix A, resulting in the following:

Pollutant	Tons Per Day
CO	265
HC (as Hexane)	15
NO	675

2. Formation of Emissions. Based on information obtained from several sources, the following generally describes the formation of emissions by gas turbines:

Carbon monoxide is formed by incomplete combustion and/or dissociation of carbon dioxide. When a turbine is idling, high emission levels are found. This is due to poor mixing, low temperatures and fuel quenching on the walls. At higher temperatures, carbon monoxide is sometimes formed at levels higher than the equilibrium indicates due to quenching from secondary combustion air and/or turbine gas expansion. Equilibrium conditions for all turbine inlet conditions are generally less than 10 parts per million.

Unburned hydrocarbon emissions result from incomplete combustion and are caused by poor mixing, fuel quenching, and inadequate fuel distribution. Combustor geometry and fuel nozzle design are the controlling factors in unburned hydrocarbon emissions. Normally, significant quantities of hydrocarbons are present only at the low power settings found at idling.

As mentioned above, carbon monoxide and unburned hydrocarbons are found in large quantities only at the lower power settings which are associated

with incomplete combustion. If the combustion efficiency can be predicted then the combined carbon monoxide-hydrocarbon concentration can also be predicted. An initial study has been made (Cornell Aero Lab Report No. NA-5007-K-1), and correlations between carbon monoxide and hydrocarbon emissions, and burner inefficiency and emission index (pounds emission per 1000 pounds fuel) have been prepared (Figures 2 and 3, respectively).

Sulfur oxide emissions from turbine combustors depend almost entirely on the sulfur content of the fuel. Since the sulfur oxides produced can cause severe corrosion to the turbine metal, fuels containing little or no sulfur are used.

Particulates (smoke) from turbines are composed of small carbon particles and some organic constituents. They are formed in the rich regions at high pressures. The most noticeable emissions of particulates generally occur during start-up and these emissions are reported to be controllable by means of several currently available techniques, including using leaner fuel mixtures in the combustion zone, and the use of burners employing premixed fuel air input.

Nitrogen oxide emissions are almost entirely associated with the fuel combustion process. Theoretical analysis and experimental results both indicate that the production of nitrogen oxides is dependent on high temperature, air-fuel ratio, residence time, burner pressure level and inlet air humidity level.

In a study performed by the Westinghouse Research Corporation, it was found the NO_x emission level also depended upon the type of fuel and the combustor exit temperature. When oil was used as a fuel, emission levels of

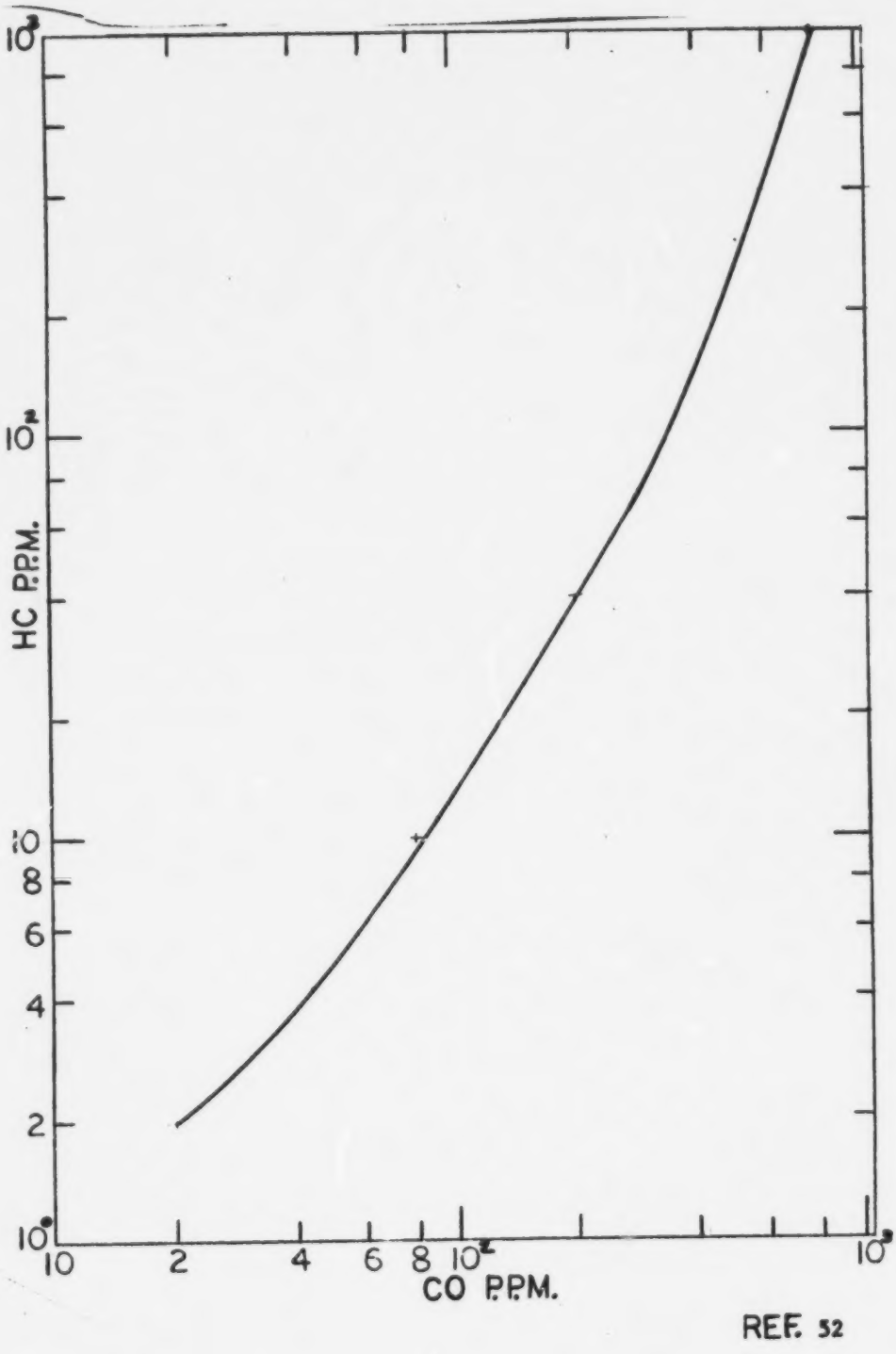

Figure 2. Carbon Monoxide Versus Unburned Hydrocarbon

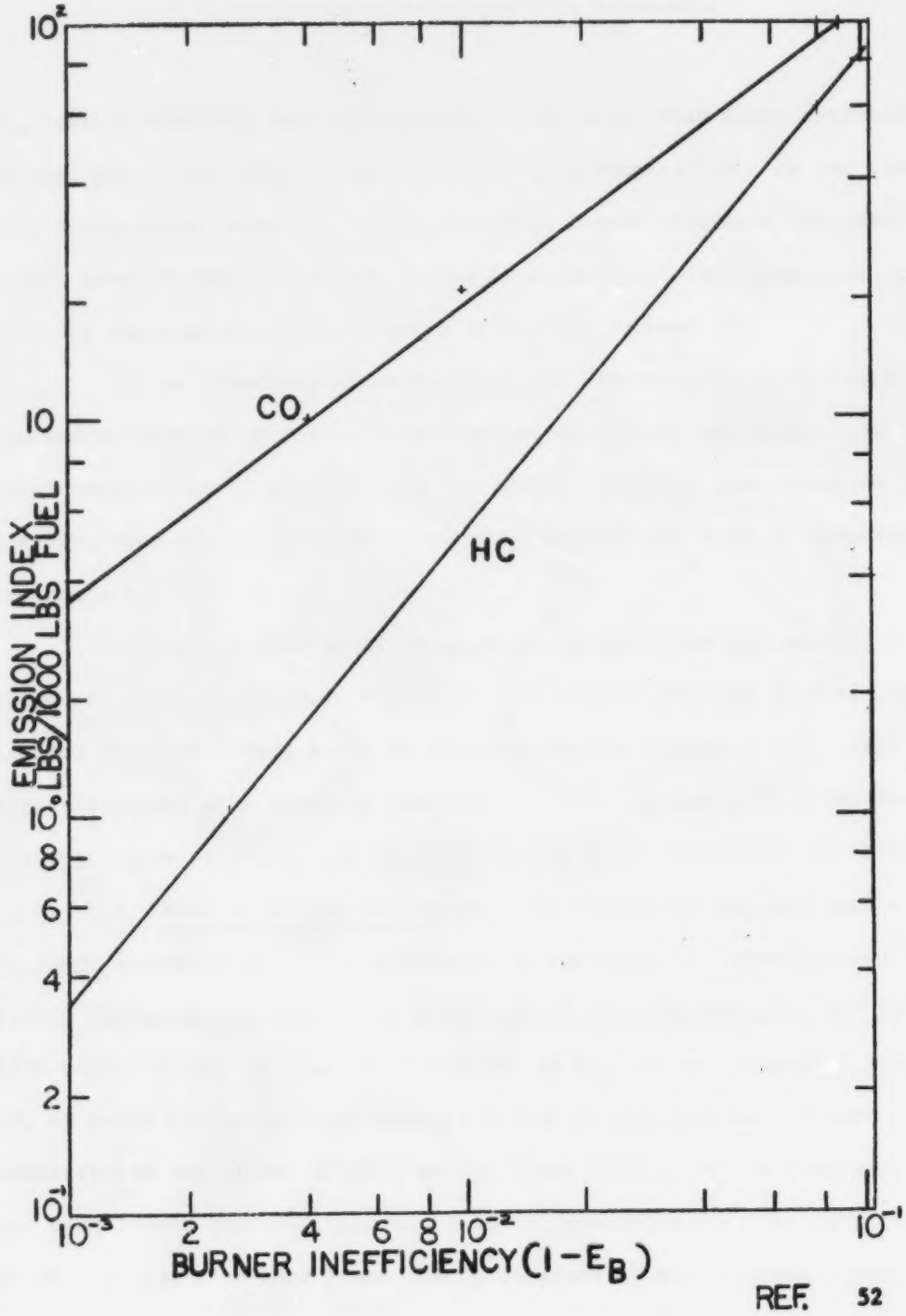

Figure 3. Carbon Monoxide and Unburned Hydrocarbon Versus Burner Efficiency

NO_x, carbon monoxide, and hydrocarbons were higher than those produced by using natural gas in the same combustor at the same temperature. As the combustor exit temperature increased, the NO_x emission levels increased, the unburned hydrocarbon level decreased, and the carbon monoxide level increased until a temperature of 1400F was reached at which point it rapidly dropped off.

An experimental correlation has been made by F. W. Lipfert, General Applied Science Laboratories, relating nitrogen oxide emissions index to combustor inlet temperature (Figure 4), and the results show the same trend as other combustors, that is, an increase in nitrogen oxide level with an increase in temperature.

In the same study nitrogen oxide emissions are related to engine pressure ratio, as shown in Figure 5. The significance of this is that the minimum emission levels occur at pressure ratios between 3 and 4 with only slight increase at a pressure ratio of 6. This implies that a low level of nitrogen oxide emissions can be achieved but with a sacrifice in efficiency.

3. Control of NO_x Emissions. The control of NO_x has been a subject of considerable study. The conclusion in the paper by Cornelius and Wade, titled Formation and Control of Nitric Oxide in a Regenerative Gas Turbine Burner, ASME paper 700708, is that the formation of NO_x can be reduced by faster quenching of gases in the primary combustion zone of the combustor (where burning temperatures are around 3500F), and by close control of the fuel/air ratio. It has been found, however, that such thermal quenching will increase the formation of CO. It has also been found that generation of NO_x is greatly increased by

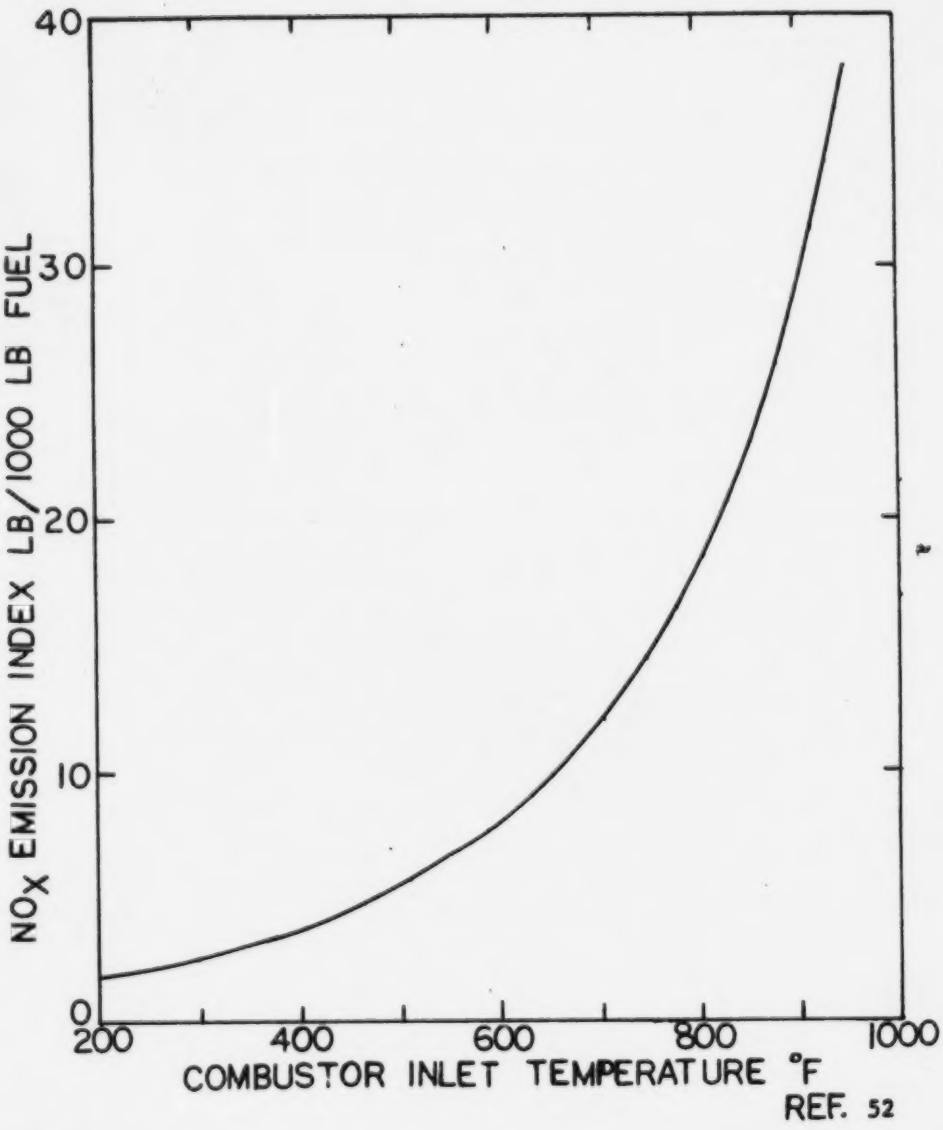

Figure 4. NO_x Emission Data Correlation

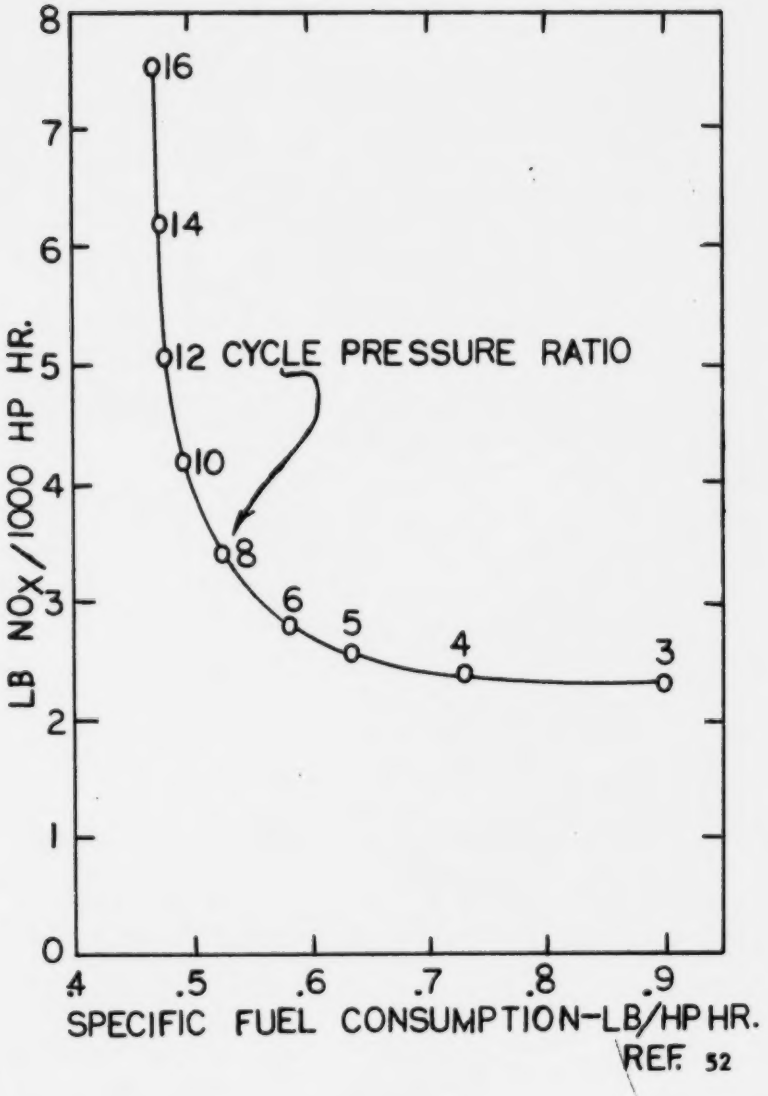

Figure 5. NO_x Cycle Optimization

increases in combustion temperature, by length of time of combustion at that temperature, and by the amount of excess oxygen. The referenced study suggests that further effort be expended on combustor design and combustion controls to further reduce the NO_x.

Because of the temperature effect on equilibrium concentrations and formation rate of nitrogen oxides, the use of water/steam injection has been found to be a possible control technique.

As mentioned previously, there is a definite trend toward use of higher and higher inlet gas temperatures to the turbine in order to achieve higher thermal efficiencies. This would probably have the undesirable effect of increasing NO_x emissions.

A review of current literature indicates that work on air pollution problems has not yet resulted in solutions, although progress appears to have been made. In view of the potential growth in the use of gas turbines, there should be continuing effort and funding for research to obtain solutions to air pollution problems from this source.

SECTION V - KILNS

In addition to its common meaning as a form of furnace, the use of the term "kiln" has been associated with dryers and ovens. In order to more closely define the area of investigation, it was decided that this part of the study would not include drying or melting tank equipment or any heating equipment with a normal operating temperature below 800F. A kiln will almost always include a system for generating its own heat and will be refractory lined. This context, then, will form the boundaries for examining the various furnaces, known as high temperature kilns according to common industry terminology.

Most of the analysis and classification developed in this section is based on an extensive literature search, as well as on information developed through contacts with manufacturers and trade associations. Information presently available on kilns is limited and incomplete. This is particularly true in the areas of such kiln characteristics as: size, production rates, fuel usage, uses of rotary kilns; production by industry utilizing various types of kilns, particularly rotary; and characteristics of air pollutant emissions. Because of this lack of information and data, the deductions reached in this phase of the study are less conclusive than those of Sections III and IV and, in particular, the determinations made concerning rotary kilns are less conclusive than those for other types of kilns.

A. TYPES, SIZES, AND MANUFACTURERS

1. Types. The major subtypes of kilns are listed on Page 58, Appendix B. These may generally be described as follows:

a. Box. This is a periodic batch type and consists of a single rectangular oven-like enclosure of limited (small) size. Generally, material is loaded into the kiln in small quantities. Such kilns can be of either the muffle type (See Figure 6), where the product is isolated from the combustion gases by an inner shell, or of the direct-fired type, where no such product protection is involved. Among other things, these kilns are used for manufacture of ceramic articles.

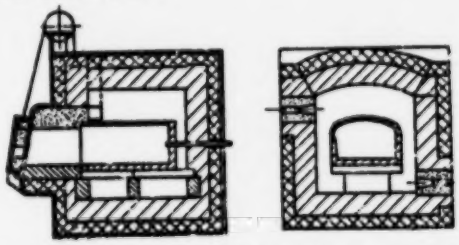

Figure 6. Small Muffle Furnace.

b. Round. This is a periodic batch type, generally quite large in diameter (up to 40 feet), and with a rounded dome. Product is stacked on the kiln floor in an open or interlaced pattern to allow the hot gases to pass through. Such kilns can be of an "updraft" or "downdraft" type (See Figure 7)

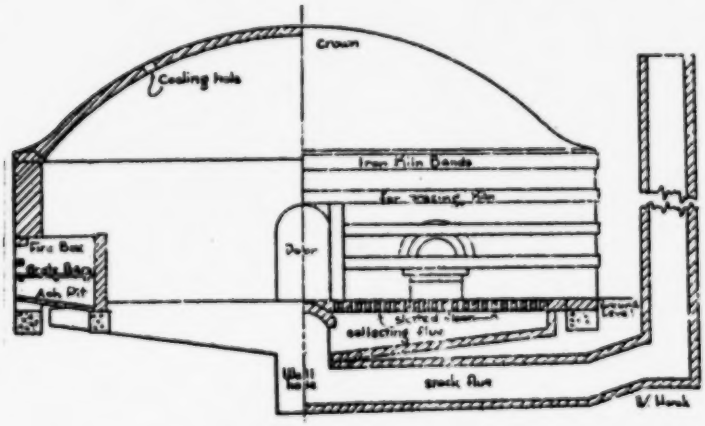

Figure 7. The round down-draft kiln, suitable for firing heavy clay products.

denoting the direction of gas circulation through the product stack. The product must remain in the kiln throughout the entire heat-up, firing, and cooling cycle. Typical applications are for brick and clay pipe manufacture.

c. Shuttle. This is a periodic batch type, generally rectangular in interior dimension, and designed to permit the product in unit load quantities to be "shuttled" in and out of the firing zone. The unit loads of product are normally handled on kiln cars. With such a kiln, it is not necessary for the product to remain in the kiln throughout the entire heat-up, firing, and cooling cycle. These kilns can be of either the muffle type or the direct-fired type. Typically, these kilns are used for brick and clay pipe manufacture.

d. Tunnel. This is a continuous type similar in construction to a shuttle kiln although usually much longer and with openings at each end (See Figure 8). This allows product in either unit loads or continuous stream to be moved through the kiln. The product can be conveyed on kiln cars, sliding

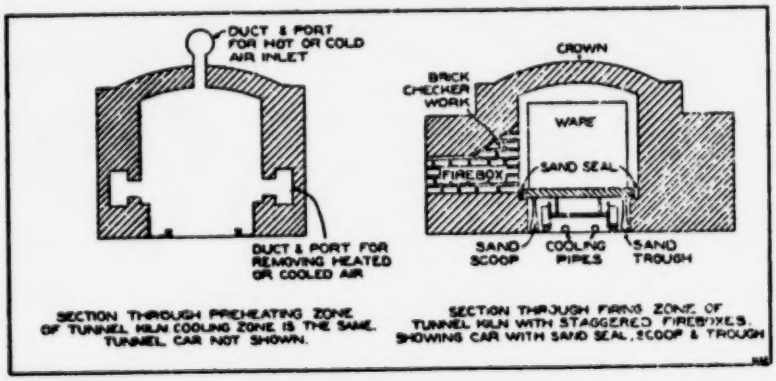
DUCT & PORT FOR HOT OR COLD AIR INLET
DUCT & PORT FOR REMOVING HEATED OR COOLED AIR
SECTION THROUGH PREHEATING ZONE OF TUNNEL KILN COOLING ZONE IS THE SAME. TUNNEL CAR NOT SHOWN.
CROWN
BRICK CHECKER WORK
WARE
SAND SEAL
FIREBOX
SAND SCOOP
COOLING PIPES
SAND TROUGH
SECTION THROUGH FIRING ZONE OF TUNNEL KILN WITH STAGGERED FIREBOXES SHOWING CAR WITH SAND SEAL, SCOOP & TROUGH

Figure 8. The tunnel kiln, as used in ceramics.

slabs, roller hearths, high temperature conveyors, walking beams, or by air flotation (for small products). Such kilns can also be of either the muffle or direct-fired type. Typical applications are for brick and clay pipe manufacture.

e. Circular. This is a continuous type, circular in shape, having a revolving hearth which conveys the product through the kiln in a circular path. It is essentially, a rotary hearth furnace (Mannheim type - See Figure 9). One application is for manufacture of lime.

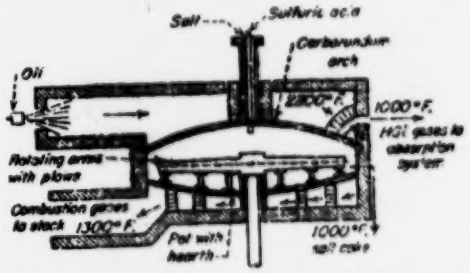

Figure 9. Mannheim-type mechanical hydochloric acid.

f. Vertical. This kiln is essentially a blast furnace known in the cement and lime industries as a "vertical" kiln (See Figure 10). This type

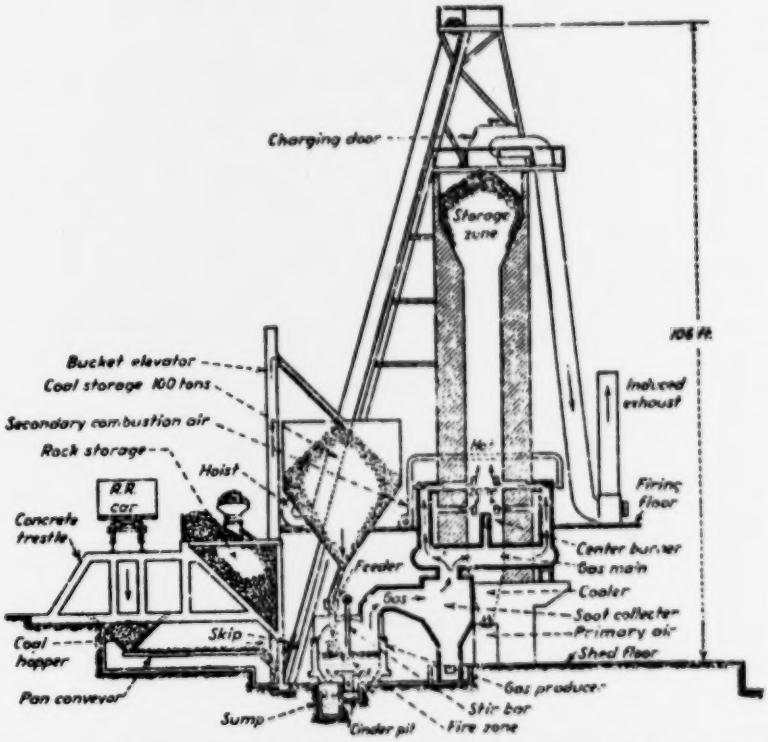

Figure 10. Gas-fired vertical lime kiln, producing 80 tons of high calcium lime per kiln per day.

of kiln allows granular product to be processed continuously or periodically through one or more vertical shafts. The materials are loaded at the top and recovered at the bottom.

g. Rotary. This is a continuous type, and is the most important and widely used type of kiln for processing granular, powdered, and liquid products. One of its major applications is in the cement industry. It is essentially a refractory lined, rotating inclined cylinder through which combustion gases and product are moved in a continuous stream (See Figure 11). These kilns can have two or three diameters within the overall cylinder length and can be fired at either end. They can also be of the batch low volume type with an opening on one end only, for infeed and outfeed on a periodic basis. Such a variety, however, represents but a minor subcategory of the rotary kiln category.

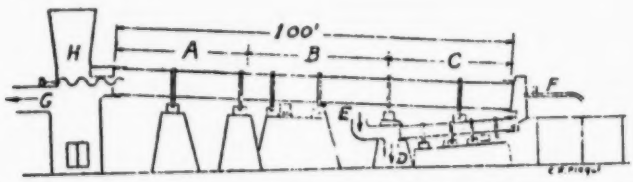

Figure 11. The rotary portland cement furnace; F, pulverized coal burner; H, feed bin with conveyor; D, discharge of clinkers; G, passage for fire gases to boilers and stack.

2. Size Ranges. According to some kiln manufacturers, "Every kiln is a specifically designed piece of equipment." There is no such thing as a "stock kiln." Kilns are designed to conform to a users specific process and production requirements, although some manufacturers do use modular sections where possible. There are no discrete and "clean" size groupings of kilns. In this study, some size data were accumulated on specific installations from manufacturers and literature sources. A summary of these data is shown on Pages 59 and 60, Appendix B.

This summary should not be regarded as being in any way all-inclusive, as it is quite limited for most subtypes.

3. Manufacturers. A list of manufacturers of kilns is shown on Pages 61 through 63, Appendix B. This list was developed from various commercial and technical sources, and should not be regarded as all-inclusive. It is believed to represent most of the larger manufacturers currently active in the industry.

Many of the kilns are installed as part of a new and complete manufacturing system or plant. Some of the manufacturers listed are in the business of providing complete systems or plants, tailor-made to customer requirements.

As may be noted from the list, most of the manufacturers specialize in providing only one or two of the subtypes of equipment.

B. USES BY FUNCTION AND INDUSTRY

The various uses of kilns, classified by function and industry, are shown on Pages 65 through 67, Appendix B. In general, their functional uses are as follows:

1. Vitrification or "firing" of preshaped and formed materials as in the making of all types of brick, clay, pipe, tile, and other ceramic shapes. This normally involves use of either box, round, shuttle, and/or tunnel kilns.

2. Chemical processing involving operations such as calcining, roasting, chloridizing, reduction, and nodulizing. Such operations involve the use of rotary, vertical and/or circular kilns.

The list of industries in which kilns are used for vitrification is well defined. In the list of industries in which kilns are used for chemical processing, the area of uses of rotary kilns is not well defined. Because of the

flexibility of the rotary kiln, it is used in many industries on both a large and small volume basis. This is further discussed in Item C of this section.

Geographic location of kilns used for vitrification of brick and clay pipe is generally determined by location of sources of raw material and, hence, tends to be away from major metropolitan centers. Locations for vitrification of tile and ceramic shapes would tend to be closer to sources of skilled labor and markets.

Geographic location of kilns used in chemical processing would tend to be close to sources of raw materials, as well as to large industrial users, especially where the output is captive.

C. INDUSTRY INFORMATION ON MARKETS AND FUEL USE

No information has been found which can be used to determine the national population of kilns by industry or by overall total. However, the estimated production tonnage of some of the industries in which kilns are used has been determined from U. S. Department of Commerce sources and is shown on Pages 65 and 66, Appendix B. This shows the major kiln subtypes used in each industry, along with such past growth rates as can be estimated.

The tonnages shown have certain limitations of accuracy but can be used to represent approximate figures. The figures for Clay Construction Products and Refractories were derived from the 1969 Census of Manufacturers which shows total units or tonnage. Some brick industry trade sources state that such figures may represent only 75 percent of the total production because of incomplete reporting. The figures for pottery and related products were derived from dollar

values of production shown in the Census of Manufacturers by using an assumed average cost per ton.

As may be seen from these figures, the major tonnages and consequent major heat and fuel requirements are in the following industries:

SIC Code No.	Industry	1000T/Year
3251111	Unglazed clay brick	15,180
3259111	Vitrified clay sewer pipe	1,800
32550XX	Clay refractory brick and shapes	2,455
3241	Cement, hydraulic	73,500
3274	Lime	21,200

In these industries, virtually all of the product is processed through kilns of various types as indicated on the summary.

It is to be noted that none of the major industries listed, other than lime (4 percent), has had a good growth rate over the years examined. Of the industries having a more moderate volume, only porcelain steatite and similar ceramic electrical products have a substantial growth rate (12 percent), although it should be noted that these two are small in terms of estimated tonnage.

No production figures are shown for those industries, other than lime and cement, which use rotary kilns because such kilns are used only for a presently indeterminate portion of the total production in such industry. However, since the rotary kiln is used in so many industries, it is believed to represent a major fuel requirement. A listing of approximately twenty products for which rotary kilns are used is shown on Pages 66 and 67, Appendix B, and further discussed in Item D.6 of this section.

An order-of-magnitude estimate of fuel consumption for kilns by type of industry, where data are available, is shown on Page 68, Appendix B. It is to be noted that for only one of these industries (cement) does fuel consumption approach 1/2 percent of the total estimated national fuel consumption of oil and natural gas, and that the total of all industries listed is less than 1 percent. However, cement and lime account for about 2 percent of the national consumption of bituminous coal. Although this ratio seems much higher, total coal consumption represents only about one fourth the total oil and natural gas consumption in terms of Btu availability.

D. AIR POLLUTANT FACTORS

The gases leaving a kiln may or may not "pollute" the air depending upon the construction and operating details of the kiln, the use to which it is put, and the nature of the process. Some pollutants can come from the burning of the fuel used to fire the kiln and other pollutants can come from the process in which the kiln is used. Indirectly-fired kilns normally keep the combustion flue gases and the process off-gases separated. Direct-fired kilns cause the flue gases and off-gases to become thoroughly mixed.

The problem in discussing air pollutants becomes one of distinguishing between fuel-emanating pollutants (particulates, SO_x, NO_x, hydrocarbons, and CO), and process-emanating pollutants (particulates, SO_x, NO_x, as well as many others).

The combustion of fossil fuels will create the following pollutants: SO_x (if the fuel contains sulfur); particulates (if the fuel contains noncombustible ash or if it undergoes incomplete combustion); hydrocarbons and CO (if it

undergoes incomplete combustion); and NO_x (if the fuel contains combined nitrogen or if certain conditions hold wherein nitrogen in the air can be fixed directly).

Apparently very little data have been obtained or published on kiln gas pollutants, as little was found during the course of this study. Because most high-temperature kilns employ direct firing, process and fuel pollutants are mixed and, therefore, good determination of pollutants is not possible from examination of flow sheets or process descriptions. This present indeterminate status of the pollutant sources and an almost total absence of data make it imperative that reliable field data be obtained before any analysis is undertaken.

Of the various subtypes of kilns, it is believed that the tunnel, vertical and rotary subtypes would represent the more significant sources of pollution from the standpoint of the greatest fuel usages and possible process pollutants. In embarking on a program of obtaining field data, therefore, it would be more productive to start with these.

A survey of the literature on various industries was undertaken to show how kilns are used and what air pollution results from their use. A discussion of these findings follows. Some of the more significant survey data are shown in Pages 69 through 73, Appendix B.

1. Clay Construction Products

a. General. This industry involves the manufacture of brick, building tile, clay pipe, and clay tile. Four types of kilns are used: box kilns for small volume production runs, round and shuttle kilns for larger volume runs and tunnel kilns for continuous production runs, such as for common brick.

Production efforts in this industry are directed toward lower manufacturing costs which tends toward high-volume, continuous production with heat recovery where feasible. Tunnel kilns appear to be the principal type used today.

Future sales are unpredictable since they depend upon the construction industry, the labor costs to install these materials, and the competition of substitutes; e.g., sand-lime brick. Sand-lime brick does not employ kilns in its manufacture.

b. Combustion and Fuels. Generally, clay kilns are fired on oil and gas (although there may still be some which use coal). Gas is preferred primarily because of its very low cost per Btu. It is a clean fuel and associated controls and handling systems are far less expensive; therefore, it would probably be the preferred fuel even if the price were higher than oil.

Clay products are fired in the temperature range of 1900F to 2500F with most firing at 2050F.

Consumption of fuels per unit weight for manufacture of these products depends upon:

(1) Design and age of a particular kiln.

(2) Product item itself; e.g., a given kiln can have a variation in heat requirements on a ratio of as much as three to one resulting from clay pipe ranging in size from 30 inches to 12 inches.

(3) Whether or not a recuperator is used.

c. Air Pollutants. Most brick and other clay structural products are made in direct-fired kilns, except that in some cases, where color or texture is important, a muffle design is used. Therefore, flue gases and kiln gases may or may not be mixed.

Various types of clays used in this industry contain a significant amount of sulfur, usually in the form of pyrites. In addition, fluorine and chlorine compounds are sometimes encountered in the clays and are sometimes applied for surface glazing in the manufacture of tile. Depending on the raw materials and process, therefore, all of these compounds could be found in the flue gases. Each case, however, must be examined separately as no further generalizations can be made at this point on an industry basis.

Recognizing that kiln and/or flue gases can contain air pollutants, several manufacturers do offer scrubbing systems to remove such pollutants from the effluent gases.

2. Pottery and Related Products. Very little information was found on kilns used in this industry and on resulting air pollutants. That which was found, however, is summarized herein.

This industry includes the manufacture of plumbing fixtures, china, porcelain, earthenware, and industrial ceramic materials. The types of kilns used are the box, shuttle, and tunnel. Generally, the sizes of kilns used are much smaller than those employed in the clay construction products industry.

As mentioned previously, the estimated tonnage of production and consequent fuel usage is low in comparison with that of the other industries in

this study; e.g., it represents less than 10 percent of the tonnage of unglazed brick.

There are special glazing and coloring compounds used which could contribute air pollutants. Some of these glazing compounds are similar to those used in the manufacture of tile. However, until actual emissions are measured and analyzed, this can only be considered a possibility.

3. Nonclay Refractories. Very little information was found on this industry. The information found, however, forms the basis for the discussion below.

This industry includes the manufacture of clay and nonclay refractories. The types of kilns used are the round, shuttle, and tunnel. Production tonnage is about 20 percent of that of unglazed brick, with about four fifths of this being clay firebrick. The remainder consists of special varieties of nonclay firebrick having higher temperature resistance and special chemical properties.

Although no specific information was found, it is believed that the air pollution emissions from clay firebrick would be similar to those from manufacture of ordinary unglazed brick.

It is also believed that the air pollution emissions from manufacture of nonclay refractory might be more severe than those for unglazed brick for two major reasons. Firstly, the firing temperature is generally much higher (2800F to 3200F versus 2000F), which possibly could lead to a higher NO_x concentration in the flue gases. Secondly, the various chemical compositions used in the bricks

could result in flue gas pollutants, such as compounds of sulfur, chlorine, and fluorine.

However, until actual emission measurements are made, these statements can be considered as only possibilities.

4. Cement

a. General. In the United States, portland cement is made in rotary kilns. Although there are probably many small kilns still in use, the trend for many years has been to very large kilns for reasons of economy. One recent installation is a kiln 570 feet in length having a daily capacity of 9700 barrels.

Since cement is an essential ingredient in all aspects of construction, its production tends to vary with that of the construction industry as a whole. Long range growth appears to be small.

There are two basic process variations in the production of cement; namely, the dry process and the wet process. Generally, the dry process uses shorter kilns. Technical changes such as using fly ash recovered from boiler houses to extend the clinker will unquestionably continue to occur, but the pace of these changes will be restricted by the existence of a very large existing installed capacity.

b. Combustion Fuels. Cement is calcined by direct flame. Calcination generally takes place at 2800F and the high temperature gases are cooled in the long kiln against the incoming cold feed.

All commercial fuels are used: coal (anthracite and bituminous), oil and gas. A national average consumption of fuel would be in the range of 3000 to 3300 Btu per pound of cement. The choice of fuel is a matter of economics and availability. Many plants operate on two different fuels and some on three.

c. Air Pollution. The cement industry has previously been examined and reported in "Air Pollution Aspects of Emission Sources: Cement Manufacturing" AP-65. In general, the major air pollutants are fines from the process. There are no other pollutants reported except for special notes on odor from some feed materials. NO_x has never been reported. SO_x is reported to condense on dust in a combined form.

5. Lime

a. General. This item is produced both as an end product and as a subproduct in the manufacture of other end products. Generally, some form of calcium carbonate is thermally decomposed to calcium oxide in the presence of burning fuel.

Over the past ten years the lime industry has shown a growth rate of 4 percent per year. While it seems probable that this rate will continue, future markets will probably change somewhat. Raw material supply will probably also change due to increasing usage of by-product calcium salts, particularly gypsum which, in turn, will influence design of kilns.

Lime kilns are currently of the rotary, vertical and circular types. Rotary kilns have been made in sizes up to 12 feet in diameter and 500 feet long and as small as 5 feet in diameter and 80 feet long depending upon

desired capacity. Vertical kiln installations usually consist of multiple shafts approximately 80 feet high by 13 feet in diameter.

The different kiln designs have evolved over the past thirty years to satisfy efficiency in lime burning, the form in which the feed material is obtained, and the economics dictated by differing fuels. For example, the old vertical kilns were suited for coke and large size limestone but do not appear to be suitable for oyster shells which are now burned in horizontal rotary kilns.

Further factors which influence changes in kiln design are price and availability of the different fuels. In the past, coal was used for burning lime but low cost natural gas and oil have made impressive inroads into this fuel market. With the price of gas before pipeline distribution at 17 cents per thousand cubic feet last year, and at 25 cents this year, and with the strong possibility of future price increases, there will probably be a shift in kiln design back to those designed for usage of coal and heavy fuel oil.

Another factor which may have a possible impact is a recent high-efficiency, vertical design from Germany, reported to give high quality using liquid fuel only. It has been built in size ranges of 100 to 700 tons per day, all of which are 120 feet high.

b. Combustion. Thermal decomposition of calcium carbonate is done in direct contact with the flame from fuel combustion. Heat economy is achieved by sending the flue gas countercurrent to the incoming stone. The availability of the entirely different fuels (gas, oil and coal) has permitted the three types of kilns to be developed competitively and contemporarily.

Decomposition of the stone takes place at 2000F for active lime and 3000F for dead-burned lime. In either case, the gas is usually cooled to about 200F, except where for process reasons, such as generating steam, it is desired at a higher temperature.

c. Air Pollution. There are very little data available on air pollutants from kilns in the manufacture of lime. The only firm statement found on air pollution from lime burning is that particulate emissions are a nuisance.

The nature of the feed and the nature of the fuel, as well as the use of the kiln gas, all can influence whether or not any air pollutants are emitted from the burning of limestone. Each situation must be examined on its own merits and no generalizations can be made, especially when the question of lime quality is involved.

It is believed that the air pollutants from lime burning, other than particulates, may not be a severe problem. This statement is based on the fact that lime is burned at a fairly low temperature and that it is being found effective for removing SO_x from stack gases of boiler plants. For reference see the article by A. V. Slack and H. L. Falkenberry titled "Sulfur-Dioxide Removal from Power Plant Stack Gas by Limestone Injection" published by Combustion, December 1969, and also EPA contracts relating to TVA Shawnee Power Station. However, as with other industries, emission measurements should be made to obtain reliable data on which to base conclusions.

6. Additional Products and Industries Using Rotary Kilns. As mentioned previously, rotary kilns are used in many and varied industries, products and processes because of their versatility in application and relatively low cost.

Also as mentioned previously, little or no information is available on the population of rotary kilns or of the production quantities of product categories involving their use.

In this study, efforts were made to ferret our those industries, products and processes in which rotary kilns are used. Approximately twenty different products were found in seven different industry categories and are shown on Pages 66 and 67, Appendix B. It is recognized that this list is by no means all-inclusive.

Efforts were also made to obtain information on the air pollutants from the use of kilns in these processes. Virtually no information was found; therefore, measurement of emissions is imperative in order to obtain reliable data from which to determine possible needs for corrective action.

The process information available for each of the processes listed has been examined to develop some suggestions as to what possible pollutant emissions may be expected from the kilns used in the processes. This information is listed on Pages 66 and 67, Appendix B and, where appropriate, is discussed below. In general, particulates will probably be produced in most of these processes along with the pollutants normally produced by combustion of fuel.

a. Sulfuric Acid and Cement. Gypsum is calcined at 2600F to 2700F to obtain an SO_2-rich gas for the purpose of producing sulfuric acid. Economic logic demands that minimal gas losses occur and that a very efficient particulate removal system be employed to remove all the dust originating in the kiln. Accordingly, this process and kiln assembly can be accurately considered to be unimportant from a pollution standpoint.

b. Iron Ore. Producing iron oxide pellets in a rotary kiln from benificiated ore presents an interesting problem. Although high temperatures are used in the kiln (2400F), the exhaust gases are cooled in a preheat furnace (1800F) and a drying furance (700F). This reuse of gas and multiple chamber separation of any dust is such a complicated and involved process that no statement can be made on possible air pollutants without measurements.

c. Alumina. The production of alumina involves calcining aluminum hydroxide at 2000F. The kiln gases can only contain the combustion gas along with water vapor and dust from the process. No data have been published which identify this dust as a pollutant. However, since the dust is a salable product, it would be expected that stack losses would be kept to insignificant levels, even though data are not available.

d. Titanium Dioxide. Titanium dioxide is produced in a manner similar to alumina at 1600F to 1700F and the air pollution problem could therefore be reasonably expected to be the same.

e. Mercury. Mercury ore (connabar) is roasted at 1100F. While it is conceivable that mercury can be in the exhaust gas leaving the collectors, no published data have been found to quantify this. Total mercury losses of 0.5 pounds per ton of ore have been reported but these losses are in the slag and spillage, as well as on the dust collectors and stack.

f. Uranium. Burning lignite to produce a uranium ore (lignite ash) will yield air pollutants to the extent that such pollutants are present in the lignite. Not much data have been published on lignite analyses.

APPENDIX A - DATA ON GAS TURBINES

EQUIPMENT TYPE Turbines - Gas

SIZE AND SUBTYPE CLASSIFICATION

CODE	SUBTYPE AND SIZE
Subtypes	
10	a. Open cycle - simple
	b. Regenerative
20	Combined cycle (exhaust to boiler)
Size Ranges	
01	Below 1,000 horsepower
02	1,000 to 10,000 horsepower
03	10,000 to 20,000 horsepower
04	Above 20,000 horsepower

EQUIPMENT TYPE Turbines - Gas

MANUFACTURERS

NAME	SUBTYPE		SIZE RANGE (1000's Hp)			
	Open Cycle	Combined Cycle	Below 1	1-10	10-20	Above 20
Code	10	20	01	02	03	04
Westinghouse Electric Corporation	X	X				L
General Electric Company	X	X		S	S	L
Worthington Turbine International, Inc. (Turbodyne)	X	X			S	L
Turbo Power & Marine Systems, Inc. (Pratt & Whitney)	X					M
Cooper-Bessemer Company	X			S	L	S
Curtis-Wright Corporation	X					S
English Electric - AEI Turbo-generators Ltd.	X				S	S
Dresser Industries, Inc.	X				S	
Ingersoll-Rand Company	X			S	S	
Clark Brothers Company	X				S	
Allison Division of General Motors Corporation	X		X	M		
Solar Division of International Harvester Company	X	X	X	L		
AiResearch Mfg. Division of Garret Corporation	X	X	X	M		
Lycoming Division Avco Corporation	X			S		
Ford Motor Company	X		X			
Motor Company	X		X			

Apparent sales factor in size category:

L - Large M - Medium S - Small

X- Relative sales not known

TRADE ASSOCIATIONS

AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)
345 East 47th St. Phone: (212) 752-6800
New York, N.Y. 10017
O. B. Schier, II, Executive Director
Founded 1880 - Members 64,125 - Staff 128 - Regions 11 - Local sections 118. Professional society of mechanical engineers (55,638). Membership also includes student members (8487) in 178 student sections. Conducts research; develops boiler and pressure vessel, and power test codes; serves as sponsor for the United States of America Standards Institute in developing safety codes and standards for equipment; maintains, with other engineering societies, a 180,000-volume library. Committees: U.S. Committee on Theoretical and Applied Mechanics; U.S. National Committee of the International Electrotechnical Commission. Maintains 15 research committees. Divisions: Air Pollution Control Group, Applied Mechanics, Automatic Control; Aviation and Space, Biomechanical and Human Factors, Design Engineering, Diesel and Gas Engine Power; Energetics, Fluids Engineering, Fuels, Gas Turbine, Heat Transfer, Incinerator; Lubrication, Management, Materials Handling Engineering; Metals Engineering, Nuclear Engineering, Petroleum; Plant Engineering and Maintenance, Power; Pressure Vessels and Piping Process Industries; Production Engineering; Railroad; Rubber and Plastics, Safety, Solar Energy Applications; Textile Engineering; Underwater Technology. Publications: (1) Mechanical Engineering, monthly; (2) Applied Mechanics Reviews, monthly; (3) Transactions (Journals of Power, Industry, Heat Transfer, Basic Engineering, Applied Mechanics, Lubrication), quarterly. Convention/Meeting: Semiannual - 1970 June 7-10, Boston, Mass., Nov. 29-Dec. 4, New York City; 1971 June 13-16, New York City, Nov. 28-Dec.3, Washington, D.C.; 1972 June 11-14, Washington, D C., Nov. 12-16, New York City, 1973 June, New York City, Nov. 11-16, Detroit, Mich.

ENGINE MANUFACTURERS ASSOCIATION
333 N. Michigan Ave. Phone: (312) 236-0633
Chicago, Ill. 60601
Thomas C. Young, Executive Director
Founded 1968 - Members 11 - Staff 2. Producers of internal combustion engines for all applications except those used exclusively for automobiles and aircraft. Committees: Emissions Standards; Noise Standards. Publication: Lubricating Oils for Industrial Engines, biennial. Supersedes: Internal Combustion Engine Institute (Founded 1933).

ENGINE GENERATOR SET MANUFACTURERS ASSOCIATION (EGSMA)
2211 Tribune Tower
Chicago, Ill. 60611
Glenn W. Bostrom, Exec. Dir.
Founded 1963. Manufacturers of devices to generate electrical power through the use of a reciprocating or rotary engine coupled to a generator. Committees: Government Liaison; Legislative; Statistics; Technical and Standards; Trade Practices; Trade Promotion. Publications: (1) Marketer and News, monthly; (2) Membership Product Directory, annual. Convention/Meeting: Semiannual - 1970 Feb., Chicago, Ill.

NATIONAL ENGINE USE COUNCIL (NEUC)
333 North Michigan Ave. Phone: (312) 236-0633
Chicago, Ill. 60601
Managed by Smith, Bucklin & Associates, Inc.
Founded 1961 - Members 70. Reciprocating and turbine engine manufacturers; engine and equipment dealers and distributors; engine accessory producers; automatic control manufacturers; lubricant suppliers; natural gas, LP-gas, and diesel fuel suppliers, and the trade press. To promote use of reciprocating and turbine engines and engine systems as prime movers.

NATIONAL ASSOCIATION OF POWER ENGINEERS (NAPE)
176 West Adams St., Suite 1411 Phone: (312) FR 2-0835
Chicago, Ill. 60603
Founded 1882 - Members 12,500 - Staff 4 - State associations 18 - Local chapters 190. Professional society of power and stationary engineers. Associate members: sales engineers and teachers of any phase of engineering. Areas of interest include air-conditioning, compressed air, electric power, refrigeration, steam, water, etc. Promotes education in the power engineering areas. Secures and enforces engineers' license laws to prevent the destruction of life and property in the generation and transmission of power and for the conservation of fuel resources of the nation. Maintains correspondence courses. Committees: Air Pollution, American Power Conference, Industrial Coal Conference, License Law; Scholarship; Water Pollution. Publications: (1) National Engineer, monthly; (2) Directory, annual. Also publishes pamphlets and produces films. Convention/Meeting: Annual - 1970 July 5-10, Miami Beach, Fla.

SOCIETY OF AUTOMOTIVE ENGINEERS (SAE)
2 Pennsylvania Plaza Phone (212) 594-5700
New York, N.Y. 10001
Joseph Gilbert, Sec.
Founded 1905 - Members 27,000 - Staff 155 - Local groups 52. Professional society of engineers in field of self-propelled ground, flight, and space vehicles; engineering students are enrolled in special affiliation. To promote the arts, sciences, standards, and engineering practices related to the design, construction, and utilization of self-propelled mechanisms, prime movers, components thereof, and related equipment. Local groups hold monthly meetings for presentation of papers and discussion of technical problems. Through Coordinating Research Council cooperates with American Petroleum Institute in research on utilization of fuels and lubricants in automotive apparatus. Presents awards and sponsors memorial lectures. Special Boards: Technical; Engineering Activity. Special Subcommittees: Aerospacecraft; Aerospace Powerplant; Air Transport; Body; Computer; Engineering Education; Materials Engineering, Farm, Construction, and Industrial Machinery; Fuels and Lubricants; Manufacturing Engineering; Passenger Car; Powerplant; Science-Engineering; Transportation and Maintenance; Truck and Bus. Publications: (1) SAE Journal, monthly; (2) SAE Transactions, annual; (3) SAE Handbook (book of standards), annual; (4) SAE Consultants, annual; (5) Advances in Engineering Series, about 4 volumes/year; (6) Technical Progress Series, about 3 volumes/year; also publishes over 100 publications dealing with automotive industry practices, about 750 technical papers annually. Formed by merger of: (1917) Society of Automobile Engineers, American Society of Aeronautic Engineers, and Society of Tractor Engineers. Convention/Meeting: Annual - always Jan., Detroit, Mich.

EQUIPMENT TYPE Turbines - Gas

PRODUCT VOLUME IN INDUSTRIES WHERE EQUIPMENT IS USED

SIC Code No.	Industry, Product and Process	Equipment (a) Subtypes Used	Annual Tonnage or Rate of Production	Indicated Growth Rate %	Time Period
	Electric Power Generation				
4911	Electric Companies and Systems	10, 20	42.2 MM Hp (1971) (b)	8.2 (Overall Industry) (c)	
2811	Telephone and Communications (Wire or Radio)	10	Small		
50XX thru 99XX	General Commercial and Government Buildings and Hospitals	10, 20	Small		
	Compressors and Electric Power Generation				
4922	Natural Gas Transmission	10, 20	2.2 MM Hp (1969) (d)		
28XX	Chemicals and Allied Products	10, 20	Small		
29XX	Petroleum Refining and Related Products	10, 20	Small		
	Pumps and Electric Power Generation				
1381	Drilling Oil and Gas Wells	10	Small		
4612	Crude Petroleum Pipelines	10	.2 MM Hp (1969) (d)		
4613	Refined Petroleum Pipelines	10			
	Pumps and Compressors				
1311	Crude Petroleum and Natural Gas (Operation of Oil and Gas Fields)	10	N.A.		

(Continued on Page 52)

EQUIPMENT TYPE Turbines - Gas

PRODUCT VOLUME IN INDUSTRIES WHERE EQUIPMENT IS USED (Continued from Page 51)

SIC Code No.	Industry, Product and Process	Equipment Subtypes Used	Annual Tonnage or Rate of Production	Indicated Growth Rate %	Time Period
	General Industry and Commerce				
	Can be used in any other industry where electric power and mechanical power is required. Uses in other fields, at present, is small		Small		

(a) For code reference see table on Page 48. Appendix A.
(b) Source No. 25
(c) Source No. 32
(d) Source No. 27

EQUIPMENT TYPE Turbines - Gas

EQUIPMENT MARKET OR POPULATION

Subtype or Size	Population*	Indicated Growth Rates
Survey in Power October 1970 Report as of 1969	Total sales 1965 through 1969	Based on 1965 through 1969 total sales, approximate population (5 year projected)
Power Generation		
01 Below 1,000 Hp	6,100 units	N.A.
02 1,000 to 10,000 Hp	900 units	7 to 8 percent per year
03 10,000 to 20,000 Hp	410 units	12 to 14 percent per year
04 Above 20,000 Hp	560 units	12 to 14 percent per year
Compressors		
02 1,000 to 10,000 Hp	1,020 units	12 to 14 percent per year
03 10,000 to 20,000 Hp	170 units	12 to 14 percent per year
	Above represents about 1/2 total installed horsepower as of end 1969	Assuming total number of installed units is 200 percent of sales in 1965 through 1969 period

* Source No. 25

EQUIPMENT TYPE AND SUBTYPE Turbine - Gas - Open Cycle (Simple and Regenerative)

SIC Code No.	Industry, Product and Process or Use	* Size Range Code	Fuel Types					Thermal Efficiency
		Approximately 80 Percent or More	Nat. Gas	Dist. Oil	Resid Oil	Com-bina-tion	Other Gases	
	Electric Power Generation							
4911	Electric Companies and Systems	04	X	X	X	X		20 - 37%
2811	Telephone and Communications	01, 02	X	X	X	X		
50XX through 99XX	General, Commercial and Government Buildings and Hospitals	01, 02	X	X	X	X		
	Compressors and Electric Power Generation							
4922	Natural Gas Transmission	02, 03	X					
28XX	Chemicals and Allied Products	02, 04	X			X	X	
29XX	Petroleum Refining and Related Products	02, 04	X	X	X	X		
	Pumps and Electric Power Generation							
1381	Drilling Oil and Gas Wells	02	X	X	X	X		
4612	Crude Petroleum Pipelines	01, 02		X	X	X		
4613	Refined Petroleum Pipelines	01, 02		X	X	X		
	Pumps and Compressors							
1311	Crude Petroleum and Natural Gas	02, 03	X	X	X	X		
	General Industry and Commerce	N.A.	X	X	X	X		

* For code reference see table on Page 48.

ORDER-OF-MAGNITUDE ESTIMATES

FUEL FOR GAS TURBINES

Assume: Total national capacity 1971 = 45,000,000 horsepower

Total national capacity - 5 to 9 years = 90,000,000 horsepower

25 percent overall thermal efficiency

Fuel heat value - 20,000 Btu per pound

Btu per horsepower = 2,545

Ratio of gas usage to oil usage in pounds = 44:56.*

Combined usage factor 1971 = 18 percent based on approximate power plant usage of 13 percent* and assumed industrial and pipeline usage of 60 percent

Combined usage factor 5 to 9 years = 24 percent based on assumed power plant usage of 20% due to increased use for base power generation

Calculation:

1971 Level

Total fuel consumption per day $= \frac{45{,}000{,}000 \times 2545 \times 24 \times .18}{20{,}000 \times .25}$

= 100,000,000 pounds

Gas consumption per day = 100,000,000 x .44 x 20

= 880,000,000 cubic feet per day

Oil consumption per day $= \frac{100{,}000{,}000 \times .56}{307}$

= 182,000 barrels per day

5 to 9 years

Total fuel consumption per day = 267,000,000 pounds

* Source No. 48

TOTAL FUEL CONSUMPTION

Based on SRI reports:

Primary Liquid Hydrocarbons

Annual consumption (estimated 1971) = 5,600 million barrels

Daily consumption (assuming 312 days per year consumption) = 18 million barrels or $5,520 \times 10^6$ pounds

Natural Gas

Annual consumption (estimated 1971) = 23,000 billion cubic feet

Daily consumption (assuming 312 days per year consumption) = 74 billion cubic feet or $3,700 \times 10^6$ pounds

Bituminous Coal

Annual consumption (estimated 1971) = 540 million tons

Daily consumption (assuming 312 days per year consumption) = 1.73 million tons = 3,460 million pounds

APPENDIX B - DATA ON KILNS

EQUIPMENT TYPE Kilns

SIZE AND SUBTYPE CLASSIFICATION

CODE	SUBTYPE AND SIZE
	Subtypes
01	Box
02	Round
03	Shuttle
04	Tunnel
05	Circular
06	Vertical
07	Rotary

EQUIPMENT TYPE Kilns

SIZE RANGES FOUND

Subtypes	Size Range	Tonnage or Units per Day	Comments
01 Box	Not available	Not available	Small for batches
02 Round	Up to 40 ft. ID	Some at 10 tons of clay pipe	
03 Shuttle	1 to 6 or more Kiln cars up to 8' width by 10' length	Up to 35,000 brick	No data on floor and wall tile and other ceramics
04 Tunnel Brick and clay tile	225 to 550 ft. long	50,000 to 400,000 brick	
Floor and wall tile	Smaller. One found at 100 ft. long	11,700 sq. ft.	Only data found
05 Circular Lime	One at 52 ft. OD	125 tons	Only data found
06 Vertical Lime	75 to 120 ft. high, 6 to 13 ft. diameter	30 to 700 tons	

EQUIPMENT TYPE Kilns

SIZE RANGES FOUND

Subtypes	Size	Tonnage or Units per Day	Comments
Sizes			
07 Rotary	5 ft. diameter by 50 ft. long to 25 ft. diameter by 750 ft. long	10 tons to 5000 tons	Smaller sizes available

Table 20-10. Typical Rotary-kiln Installations* (1)

Size, diam. × length	Usual No. of supports	Range of motor hp. to operate†	Nominal 24-hr. capacities‡			
			Portland cement, 376-lb. bbl.		Lime, net tons	
			Dry process	Wet process	Lime sludge	Limestone
5 × 80 ft.	2	5–7.5	140	100	10	16
6 × 70 ft.	2	7.5–15	190	135	15	24
7 × 70 ft.	2	15–20	275	200	20	35
5 ft. 6 in. × 180 ft.	4	15–20	285	250	30	45
7 × 120 ft.	2	15–25	475	340	35	55
7 ft. 6 in. × 125 ft.	2	20–30	575	415	40	70
6 × 220 ft.	4	20–30	420	375	45	65
8 × 140 ft.	2	25–30	750	540	55	90
9 × 160 ft.	2	30–50	1100	800	80	130
8 ft. 6 in. × 185 ft.	4	30–50	1125	810	80	135
10 × 150 ft.	2	40–75	1300	950	...	145
10 × 175 ft.	2	50–75	1500	1100	...	155
8 × 300 ft.	5	50–75	1150	1000	110	160
7 ft. 6 in. × 8 ft. 6 in. × 320 ft.	5	50–75	1175	1020	115	165
7 ft. 6 in. × 10 ft. × 8 ft. 6 in. × 300 ft.	5	50–75	1175	1020		
10 × 11 × 175 ft.	2	50–75	1650	1200	120	180
10 ft. 6 in. × 185 ft.	2	50–75	1860	1300	130	190
11 × 175 ft.	2	60–100	1850	1375	...	205
8 ft. 6 in. × 10 ft. × 8 ft. 6 in. × 300 ft.	5	50–75	1400	1200	140	200
8 × 10 × 300 ft.	5	50–75	1425	1225		
9 ft. 6 in. × 265 ft.	4	60–100	1500	1300	150	215
9 × 10 ft. 6 in. × 9 ft. × 325 ft.	5	60–100	1700	1500	175	240
10 ft. 6 in. × 250 ft.	4	60–100	1750	1525		
9 ft. 6 in. × 11 ft. × 9 ft. 6 in. × 300 ft.	5	60–100	1800	1550	190	250
10 × 300 ft.	5	75–125	1900	1650		
9 ft. 6 in. × 11 ft. × 9 ft. 6 in. × 375 ft.	6	75–125	2025	1800	225	300
11 × 300 ft.	5	75–125	2400	2100	240	320
11 ft. 6 in. × 300 ft.	4	100–150	2600	2250	250	325
10 ft. 6 in. × 375 ft.	5	100–150	2700	2400	275	350
11 ft. 3 in. × 360 ft.	5	125–175	2900	2500		
11 ft. 6 in. × 475 ft.	7	150–250	4000	3500	375	450
12 × 500 ft.	8	200–300	4600	4000	425	500

* Allis-Chalmers Manufacturing Co.
† Power requirements vary according to size of kiln, character of material handled, and method of operation.
‡ Capacities indicated are conservative, and apply to normal operation at sea level. Corrections would apply at increased altitudes, and for differing methods of operation.

(1) Source No. 15

EQUIPMENT TYPE Kilns

MANUFACTURERS	SUBTYPE MANUFACTURED						
	Box 01	Round 02	Shuttle 03	Tunnel 04	Circular 05	Vertical 06	Rotary 07
Allis Chalmers Milwaukee, Wisc.				C,O,G			X
Bartlett-Snow, A Bangor Punta Co. Cleveland, O.							O,G
Bickley Furnaces, Inc. Philadelphia, Pa.	G		O,G	O,G			
Buffalo Tank Div. Bethlehem Steel Corp. Dunnelson, N.J.						X	X
Calcimatic, Ltd. Toronto, Ont.					X		
Dispatch Oven Co. Minneapolis, Minn.				O,G			
Dravo Corp. Pittsburgh, Pa.						G	
Ferro-Allied Engrg. Div. Cleveland, O.	G		X	G			
Harrop Ceramic Service Co. Columbus, O.	O,G		O,G	O,G			
Hendryx & Assoc. Pittsburgh, Pa.			O,G	O,G			
Interkiln Engineering, Inc. Houston, Tex.				G			

Code: C - Coal fired
G - Gas fired
O - Oil fired
X - Fuel type not known

EQUIPMENT TYPE Kilns

MANUFACTURERS	SUBTYPE MANUFACTURED						
	Box 01	Round 02	Shuttle 03	Tunnel 04	Circular 05	Vertical 06	Rotary 07
Ipsen Industries, An Alco Standard Co. Pecatonica, Ill.			G	G			
Keller Corp. Philadelphia, Pa.				O,G			
Kennedy Van Saun Corp. Danville, Pa.						O,G	O,G
Lindberg Hevi-Duty, Div. of Sola Basic Industries Chicago, Ill.	X			X			
Lingl, Inc. Dresden, Tenn.				O,G			
Mine & Smelter Supply Co., Inc. Denver, Colo.				G			
Ohio Kilns Granville, O.			X,G	O,G			
Pomona Pipe Products Co. Pomona, Calif. Fla., Mo.		G					
Selas Corp. of America Dresher, Pa.			X	X		X	
F. L. Smidth & Co.							G
Southwestern Zone Kiln Co. Snyder, Tex.				G			
Stansteel Corp., Subsid. of Allis-Chalmers Los Angeles, Calif.							X

EQUIPMENT TYPE Kilns

MANUFACTURERS	SUBTYPE MANUFACTURED						
	Box 01	Round 02	Shuttle 03	Tunnel 04	Circular 05	Vertical 06	Rotary 07
Swindell-Dressler Pittsburgh, Pa.			O,G	O,G			
Traylor Engineering and Manufacturing Co., Div. of Fuller Co. Allentown, Pa.							O,G
Vulcan Iron Works, Inc. Wilkes-Barre, Pa.						O	O

EQUIPMENT TYPE Kilns

PRODUCT VOLUME IN INDUSTRIES WHERE EQUIPMENT IS USED

Code Nos. SIC Ind.	Code Nos. SIC Prod.	Industry, Product and Process	(a) Equipment Subtypes Used	Annual Tonnage or Rate of Production	Indicated Growth Rate %/Yr.	Indicated Growth Rate Time Period
		Vitrification				
		Clay Construction Products		1970 (b) 1,000 T/Yr.		
325	1111	Unglazed Brick	02,03,04	15,180	-3	1965-70
325	1211	Structural Clay Tile	02,03,04	148	-9	1965-70
325	9111	Vitrified Clay Sewer Pipe	02,03,04	1,800	0	1965-70
325	1231	Facing Tile and Brick		602	-9	1965-70
325	1251	Facing Tile (Unglazed)		1	--	1965-70
325	3000	Clay Floor and Wall Tile	01,03,04	372	-2	1965-70
325	3015	Glazed Floor and Wall Tile	01,03,04	285	-4	1965-70
325	071	Quarry Tile		42	0	1965-70
325	053	Unglazed Ceramic Mosaic Tile		46	-2	1965-70
		Refractories - Clay and Non-clay				
		Clay:				1966-70
325	50XX	Brick and Shapes (fire-clay)	02,03,04	2,455	-4	
325	50XX	Insulating Fire Brick and Shapes	02,03,04	133	-7	
		Non-clay:				
329	7XXX	Brick and Shapes	02,03,04	542	-9	
		Pottery and Related Products		1969 (MM $)		
326	10	Vitreous and Semi-vitreous Plumbing Fixtures, Access and Fittings	03,04	191.2 (d) (382)	4	1964-69

(Continued on Page 65)

EQUIPMENT TYPE Kilns

PRODUCT VOLUME IN INDUSTRIES WHERE EQUIPMENT IS USED (Continued from Page 64)

Code Nos.		Industry, Product and Process	(a) Equipment Subtypes Used	Annual Tonnage or Rate of Production	Indicated Growth Rate	
SIC Ind.	SIC Prod.				%/Yr.	Time Period
326	20 & 30	Vitreous China and Porcelain Table and Kitchen Articles and Earthenware Table and Kitchen Articles	01,03,04	138.5 (277) (d)	3	1964-69
326	40	Porcelain Steatite and Other Ceramic Electrical Products	01,03,04	219.6 (440) (d)	12	1964-69
326	90	Pottery and Ceramic Products, N.C.C.		102.7 (204) (d)	2	1964-69
		Chemical Processing		1,000T/Yr. (e)		
324	1	Cement, Hydraulic	07	73,500	.5	1968-72
327	4	Lime	06,07	21,200	4	1960-70

(a) For code reference see table on Page 58, Appendix B.
(b) Source No. 4
(c) Source No. 5
(d) Assuming a product value of $500 per ton, this represents an order-of-magnitude estimate of 1,000 T/Yr.

DATA Rotary Kiln

Product	Process	SIC No.	Temperature Degrees F.	Possible Process Pollutants	Heat Requirements Btu/Lb.
Titanium Dioxide	Calcining	2819	1652	Particulate	
LiOH		2819	1600	Particulate	
Sulfuric Acid and Cement	Gypsum Calcining	2819 & 3240	2600 to 2700		3,000
Sulfuric Acid and Coke	Chemico sludge Conversion	2819			
Sodium Dichromate	Roasting	2819	2200	Particulate	
Cement	Dry	3240		Particulate	2,000,000 Btu Per Barrel (376 Lb.) 5,300
Cement	Wet	3240		Particulate	687,000 Btu Per Barrel with Preheater 1,800
Lime	Burning (Calcining)	3270		Particulate	
Perlite	Popping (Calcining)	3295		Particulate	
Magnesia	Calcining $MgCl_2$	3295	1000 to 1300	Hcl	2,200 (I.M.C.)
	Calcining $MgSO_4$		2900 to 3000	NaCl, SO_2	
Magnesia	Calcining Magnesium Hydroxide	3295	<3300	Particulate	
Sodium Tripolyphosphate	Calcining	3295		Unknown	
Barium Carbonate	Calcining	3295		Particulate	

(Continued on Page 67)

DATA Rotary Kiln

(Continued from Page 66)

Product	Process	SIC No.	Temperature Degrees F.	Possible Process Pollutants	Heat Requirements Btu/Lb.
Magnesia	Calcining Dolomite	3295	3300 (dead burn) 2000 (soft)	Particulate	4,000 3,875
Iron Ore	Pelletizing	3312	2400	Particulate and Unknown	300 (pellets)
Alumina	Calcining	3334	2000	Particulate	
Uranium	Calcining Lignite Containing U_3O_8	3339		Particulate	
Mercury	Roasting Cinnabar	3339	1100	Hg	
Molybdenum Oxide	Roasting	3339	1475	Particulate	

ORDER-OF-MAGNITUDE

FUEL REQUIREMENTS Kilns

Industry	Annual Production 1000T	Btu Per Lb.	Lb. Fuel Per Day (312 Days Per Year)	Percent of Total Oil and Fuel Consumption	Percent of Total Bituminous Coal Consumption
Unglazed Brick	15,180	900 to 2,000 Use 1,500	7.5×10^6 (a)	.08	
Vitrified Clay Sewer Pipe	1,800	1,500 to 5,500 Use 3,500	2.0×10^6 (a)	.02	
Clay Refractory Brick and Shapes	2,455	N.A.			
Cement, Hydraulic	73,500	1,800 to 5,300 Use 3,300	77.8×10^6 (b)	.45	1.80
Lime	21,200	1,750 to 3,500 Use 2,000	13.6×10^6 (b)	.08	.32

(a) 100 percent of this assumed oil and gas

(b) 50 percent of this assumed oil and gas

EQUIPMENT TYPES AND SUBTYPES See Below

Industry, Product and Process or Use	SIC Code	Size Range Approximately 80 Percent or More of Total	Fuel Types				Thermal Requirements	Temperature Range Degrees F
			Nat. Gas	Oil	Coal	Other		
Box Kilns								
No information found								
Round Kilns								
Clay Construction Products								
Vitrified Clay Sewer Pipe								
Pomona Pipe Products Co.	325 9111	40 feet diameter Largest in U.S.	X				1,500 to 2,100 Btu per pound	2,000
Eastern Illinois Clay Products Co.		10 ton per day						2,000
General							Same around 5,500 to 6,000 Btu per pound	

EQUIPMENT TYPES AND SUBTYPES Shuttle Kiln

Industry, Product and Process or Use	SIC Code	Size Range Approximately 80 Percent or More of Total	Fuel Types				Thermal Requirements	Temperature Range Degrees F
			Nat. Gas	Oil	Coal	Other		
Clay Construction Products	325							
Unglazed Brick	325 1111							
Abilene Brick Co.		62 feet long 35,000 barrels per day						1,830
Comfort Brick & Tile Co.		48 feet long	X					
Clay Floor and Wall Tile - General	325 3000							2,050
Vitrified Clay Sewer Pipe - General	325 9111							2,100
Refractories - Clay and Non-clay								
Clay: Brick and Shapes	325 30XX							2,450
Non-clay: Alumina - General	329 7XXX							2,850
J. H. France Refractory Co.		45 feet long	X					
Non-clay: Basic	329 7XXX					X‡		3,250
Pottery and Related Products	326							
Vitreous Plumbing Fixtures - General	326 10							2,475
Porcelain, Steatite and Other Ceramic Electric Products						X‡		3,000

‡ - O_2

EQUIPMENT TYPE AND SUBTYPES Tunnel Kilns

Industry, Product and Process or Use, or Manufacturer	SIC Code	Size Range Approximately 80 Percent or More of Total	Fuel Types				Thermal Requirements	Temperature Range Degrees F
			Nat. Gas	Oil	Coal	Other		
Clay Construction Products	325							
Unglazed Brick	325 1111							
Chattahoochee Brick Co.		523 feet long 380,000 brick/day	X					
Cherokee Brick & Tile Co.		274 feet long 104,000 brick/day	X				950 Btu per pound	
Denver Brick & Pipe Co.		535 feet long 102,000 brick/day						2,100
New Jersey Shale Brick & Tile Co.		280 feet long 140,000 brick/day	X					
Interstate Brick Div. Entrada Industries		445 feet long 100,000 brick/day						
Ottumwa Brick & Tile Co.		258 feet long 80,000 brick/day						1,940 Buff 2,035 Ivory 2,100 Grey
Red River Brick & Tile Co.		248 feet long 55,000 brick/day						
Pine Hall Co.		400 feet long 100,000 brick/day						
General							800 to 1,000 Btu per pound	
Vitrified Clay Sewer Pipe	325 9111							
Pacific Clay Products Co.		328 feet long by 10 feet wide	X				1,930 Btu per pound	
United Clay Pipe Co.		413 feet long	X					
Clay Floor and Wall Tile	325 3000	100 feet long 11,000 sq.ft./day						2,450

EQUIPMENT TYPE AND SUBTYPE See Below

Industry, Product and Process or Use	SIC Code	Size Range Approximately 80 Percent or More of Total	Fuel Types				Thermal Requirements	Temperature Range Degrees F
			Nat. Gas	Oil	Coal	Other		
Vertical Kilns								
Lime	3274						2,000 Btu per pound	2,000 to 150
U.S.Steel			X					2,300 to 150
Mfgr: Vulcan Iron Works Co.		13 feet diameter by 75 feet high 30T per day	X	X	X			
Mfgr: Kennedy Van Saun Co. (Schmid-Hofer kiln)		3 shafts 6 feet diameter by 120 feet high 100T per day to 12 feet diameter by 120 feet high 700T per day					1,700 to 3,500 Btu per pound	
Circular Kilns								
Lime	3274							
Ash Grove Lime & Portland Cement Co.		52 feet OD 125T per day						2,250

EQUIPMENT TYPE AND SUBTYPE Rotary Kilns

Industry, Product and Process or Use	SIC Code	Size Range Approximately 80 Percent or More of Total	Fuel Types				Thermal Requirements	Temperature Range Degrees F
			Nat. Gas	Oil	Coal	Other		
Cement	3241							
Dry Process - General		17.5 diameter by 590 length						2,800
Dewey Rocky Mtn. Cement Co.		17.3 diameter by 490 length						
Wet Process - General		25 diameter by 750 length						
Alpha Portland Cement		440 length						
Lime	3274						2,000 Btu per pound	
Minerals and Earths	3295							
Molybdenum Oxide		6 diameter by 60 length						1,475
Climax Molybdenum Co.								
Magnesia from Dolomite			X				4,000 Btu per pound	2,000 to 3,000
Kaiser Refractories								
Blast Furnaces, Steel Works	3312			X				
Iron Ore		17 diameter by 115 length					300 Btu per pound (pellets)	2,400
Empire Iron Mining								
Primary Smelting of Non-Ferrous Metals	3339							
Mercury								
New Indra Mining & Chemical Co.		5 diameter by 56 length		X				1,100

APPENDIX C - BIBLIOGRAPHY

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